

TEAM TERRAMAX

DARPA GRAND CHALLENGE 2005

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1. Abstract

Team TerraMax is made up of Oshkosh Truck Corporation, Rockwell Collins and the University of Parma, Italy. The TerraMax vehicle is provided by Oshkosh Truck and is based on Oshkosh Truck's Medium Tactical Vehicle Replacement (MTVR) defense truck platform that was designed for the US Marine Corps. Rockwell Collins is developing the autonomous Vehicle Management System (VMS), which includes vehicle sensor management, navigation and control systems. University of Parma is providing the vehicle's stereo vision system. Team TerraMax possesses a unique synergy with DARPA's goal to provide driverless supply lines to the U.S. military.

1.1 Introduction

Oshkosh Truck Corporation, along with partners Rockwell Collins and the University of Parma, Italy, are preparing the TerraMax™ autonomous vehicle to participate in the 2005 DARPA Grand Challenge Event on October 8, 2005. Thousands of man-hours have gone into the design and testing of this autonomous vehicle, along with thousands of miles of autonomous vehicle testing.

1.1.1 Vehicle Description

The TerraMax vehicle is based on Oshkosh's Medium Tactical Vehicle Replacement (MTVR) defense truck platform. The MTVR was designed for the US Marine Corps with a 70% off-road mission profile. It can carry a 7.1-ton payload off-road or a 15-ton payload on-road.

All-wheel drive, TAK-4™ independent suspension, and central tire inflation make rocks, dips, holes and crevasses easier to handle. And the truck can handle 60% grades and 30% side slopes. A 425-hp Cat C-12 engine powers the truck.

1.1.1.1 Vehicle Overview

The TerraMax MTVR is a model MK23 Standard Cargo Truck that was built in 1999 by Oshkosh Truck. It was chosen for the DARPA Grand Challenge (DGC) because of its proven off-road mobility, as well as for its direct applicability to potential future autonomous operation in military supply convoys.

For the DGC event, the vehicle cab and exhaust stack will be shortened to meet the requirements of the course. The vehicle weighs approximately 30,000 pounds, is 27 feet long, and has a 16-inch minimum ground clearance. It has a top speed of 65 mph and on-road range of 300 miles. The vehicle can easily be switched from autonomous mode to manual mode to allow the vehicle to be driven normally when autonomous mode is not needed.

The TerraMax vehicle is wholly owned by Oshkosh Truck, and does not utilize any government owned equipment. The wrecker support vehicle and the ISO container mobile command center also do not utilize any government owned equipment.

Two significant vehicle upgrades from the 2004 TerraMax entry are the addition of rear-wheel steering and a sensor cleaning system.

1.1.1.2 Rear-Wheel Steering

Rear steer has been added to TerraMax to give it a 29-foot turning radius. This will allow the vehicle to negotiate tighter turns without needing to back up as often. The steering system is the same basic system that is used on the MTRV tractor variant.

1.1.1.2 Sensor Cleaning System

This system keeps the lenses of the TerraMax sensors free of debris such as dust, water, and mud. The main components of this system are: Cleaning Controller, Valve Array, and Washer Tank. The Cleaning Controller controls the sequence and duration the sensors are dusted, washed, and dried. The Valve Array has electrically controlled valves that pass pressurized water and air through pattern nozzles to the sensor lenses. The Washer Tank is a 150-gallon tank that stores pressurized water for cleaning the sensor lenses.

The System has two primary modes of operation, Auto Dust/Dry and Command Wash & Dry. Auto mode blasts the sensor lenses with air to remove dust or dry water drops in a programmed pattern. A signal from the Vehicle Manager will start the Command mode that washes and dries each sensor in a programmed pattern.

1.1.2 Vehicle Management System

The Vehicle Management System (VMS) consists of hardware and software components that together provide an extensive set of autonomous capabilities. In order to accomplish this, the VMS interfaces with the vehicle systems and all onboard sensors. The primary commands to the vehicle interface are throttle, brake, steering, and transmission.

The hardware was selected specifically for the DARPA Challenge race conditions with consideration for withstanding the hot desert conditions and the ruggedness required for off-road high and low frequency vibration. Dust resistance was considered to a lesser extent as all the computers are housed in a closed container which is cooled with a closed-loop, filtered, air-conditioning system.

The general architecture for the VMS software is a set of applications that communicate to each other over a 100BaseT Ethernet network utilizing TCP and UDP protocols and a commercial Ethernet switch. The VMS software has the key role of performing all autonomous behavior and interfacing to numerous Line Replaceable Units (LRU) and the key vehicle systems. The software applications are as follows:

- Vehicle control – controls and receives feedback from the throttle, brakes, and steering in order to control the vehicle while in autonomous mode.
- Real time path planner – computes the real time path utilizing the desired path while avoiding the obstacles along the desired path

- Obstacle detection – uses LIDAR and Stereo Vision to detect positive and negative obstacles. Filters and confidence logic are used to merge the obstacle data from the various sensors into a single obstacle database used by the real-time path planner.
- Behavior management – decides what mode the vehicle should be in based on the current conditions of the other functions
- Navigation – computes present position and provides a dead reckoning function
- Sensors – are divided into two categories, navigation and perception.

A system management function is also implemented that provides a user interface for execution control and status display for the VMS applications. Once the system has been initialized, the system manager is no longer needed for the VMS to operate and is therefore not included as one of the VMS applications. The software architecture can be viewed in Figure 1.

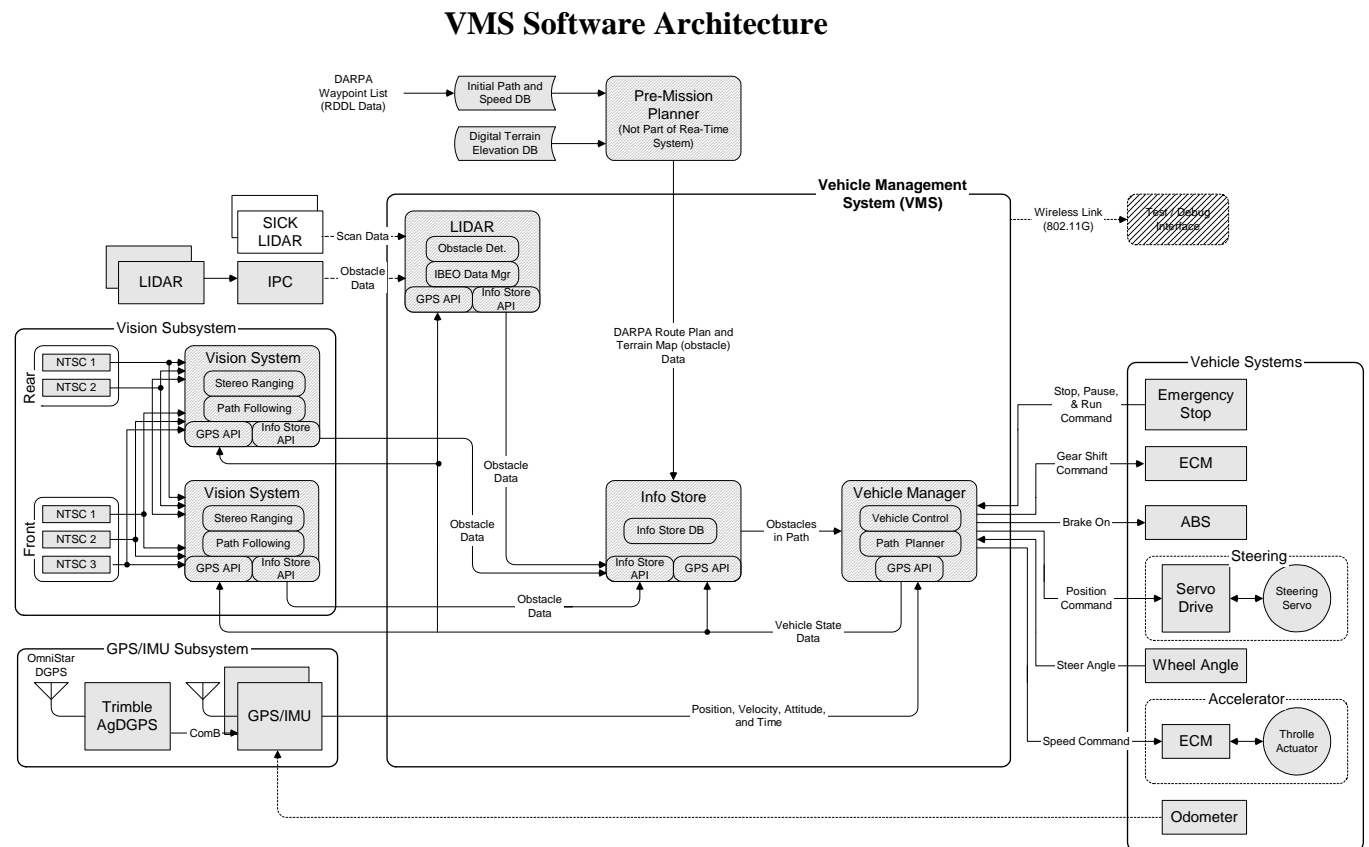


Figure 1. VMS Software Architecture

The following sections of this paper will go into further detail on each of the VMS functions.

1.1.2.1 Vehicle Control

The vehicle control function of the VMS provides the MTRV control actions that emulate the actions a human would perform when driving the truck. The controls provided by the VMS are

steering, throttle, brake, and transmission control.

Steering control is provided through an electronic servo connected directly to the MTRV steering gearbox. The standard MTRV steering gearbox has dual inputs so the steering servo for autonomous operation and hand wheel are both connected to the steering gear allowing the steering control to be switched between manual and autonomous operations without changing mechanical linkages.

The steering control function is responsible for providing wheel angle commands that guide the vehicle to the path defined by the real-time path planner. This is accomplished by computed deviations from the desired path and converting the deviations to steer angle commands that are sent to the steering servo. The steering control uses a capture and track steering control modes. Capture steering control is used for initial course capture and track steering control is used during normal operation. Capture and track control modes are automatically selected based on current conditions.

The capture controller uses course error as the control parameter. The controller creates a steer angle command that aligns the ground track of the vehicle with the direct bearing to the active (TO) waypoint. This type of control is sometimes referred to as homing control since the path followed is uncontrolled and the path to the TO waypoint may not be a straight line. Capture conditions occur during initial course capture so the capture controller is only active if certain conditions exist at the time the autonomous mode is first activated.

The track controller uses linear cross track deviation and cross track deviation rate to align the vehicles path along the ground with the active TO waypoint course. Track angle error and steer angle command limiters are used to limit the commanded steer angle to values that are achievable by the vehicle. The command limiters incorporate vehicle dynamic limits with margins built in to ensure the vehicle does not get into an unsafe condition. This also means that the vehicle operates at levels below its maximum dynamic capability when in autonomous mode. Turn anticipation for waypoint sequences is also used so the transition onto the new course is accomplished without overshoots.

The throttle controller interfaces directly to the electronic engine control unit through a digital PWM interface. The throttle controller is responsible for controlling the vehicle's speed to the desired speed specified by the path planner. This is accomplished primarily through throttle position control but engine and service brakes are also used in certain situations to manage the speed.

The throttle position control uses proportional and integral control. Reset conditions to the throttle position are provided for transmission up shift and down shift and to activate the engine brake. Engine brakes are activated during engine idle so throttle position overrides are used when engine brakes are required. Throttle position faders are used to reactivate the throttle position control when the engine brake is disabled. Engine and service brakes are used primarily to control speed on steep grades and for speed management during deceleration.

The brake controller provides an analog signal to a pressure actuator connected to air brake system (service brakes). The throttle and behavior control functions provide brake actuation

parameters to the brake controller and the brake controller determines the pressure actuator signal. The brake control parameter provided by the throttle control function is speed deviation that is used by the brake controller to provide a brake application that is proportional to the speed deviation. Behavior control provides brake override signals for emergency stop (e-stop), e-stop pause, and other special situations requiring speed control or position holding. The emergency stop condition results in a full brake command. Brake modulation to limit slipping in full brake conditions are provided by the Anti-lock Brake System (ABS) system that is part of the basic MTVR.

The MTVR has a seven speed automatic transmission. The transmission control function provides forward, neutral, and reverse gear control for the automatic transmission. The selection of the transmission gear is through a digital signal to the transmission control unit. The transmissions controller receives a desired gear signal from the behavior control function and converts the desired gear into the digital interface to the transmission. Behavior control uses the actual gear position to determine allowable state transitions and to prevent transmission faults due to incorrect gear selection sequences.

All of the control signals used in the vehicle are designed so the vehicle can be driven manually or autonomously through a single autonomous/manual switch on the dash.

1.1.2.2 Real-time Path Planner

The real-time path planner is responsible for deriving the desired trajectory of the vehicle and providing that trajectory to the vehicle control function. The trajectory includes a desired path along the ground as well as the desired speeds and boundary area. The desired trajectory is derived using the path and speed constraints contained in the DARPA RDDF file.

The RDDF route contains a list of waypoints that define a path along the ground, a path boundary, and maximum speed for each leg of the path. The real-time path planner provides reactive path corrections to this nominal path to account for current conditions, such as vehicle dynamic limits, obstacles, road edges, terrain grade, etc.

The path planner implements a tree algorithm that branches from the base at the current TO waypoint. Constraints for path boundary and speed are applied to the tree build function so the tree size is bounded by the constraints. Branches of the tree are computed using a model of the steering system and vehicle dynamics to insure that the candidate paths are drivable.

Once built, the tree represents a series of candidate paths, one of which is selected as the path to be used by the vehicle control. Selection of the best path from the candidate paths is based on a scoring algorithm that considers distance from the route centerline, path curvature, obstacle avoidance, boundary area constraints, and other factors. Over 2000 candidate paths are evaluated each planning cycle to determine the best path.

The real-time path planner also contains a speed management function that adjusts the speeds as necessary to account for path geometry and current conditions. The initial desired speed is set to the RDDF speed constraint for the leg and the speed management function reduces the speed necessary.

During normal operation, the path planner plans the trajectory starting at the current TO waypoint. Under certain conditions, the path origin is changed to account for replan conditions. The path planner accepts signals from the behavior control function to determine the origin of the new path.

1.1.2.3 Obstacle Detection

LIDAR and vision sensors are used to detect obstacles in front and behind the vehicle. Obstacles detected by the sensors are registered to the vehicle navigation position and stored in an obstacle database. The real-time path planner queries the database to determine if obstacle collisions occur on the proposed paths.

Several different types of obstacle clearance information are provided to the path planner to aid in path selection. Obstacle collision information is reported by the database in terms the closeness of the object collision to the proposed path. Buffer regions of various sizes are used to determine the collision proximity relative to the path.

Bearing and distance to the nearest collision is provided by the obstacle database that is an indication of the proximity of the obstacles to the proposed path. Obstacle distance is used primarily in the speed manager function to lower the speed if an obstacle is in close proximity to the vehicle's planned path.

Road and cliff edges are handled as special cases by the obstacle database. Since the consequences to the vehicle of breaching a cliff edge are very severe, additional weight to negative road/cliff edges are used. The database also reports if any negative road/cliff edges are in the immediate area that is used by the speed manager to reduce speeds accordingly.

The path planner and vehicle control are not directly coupled so there are instances where the vehicle is not exactly on the planned path. There are situations when a valid path is planned which avoids all obstacles but the vehicle will hit an obstacle on its current path. To account for this condition, an immediate collision function is provided that evaluates the current vehicle state and provides an immediate collision signal to behavior control if a collision is eminent. Behavior control uses that signal to determine the required vehicle response.

The obstacle database is implemented using an open source MySQL database. Geographic queries built into MySQL are used to perform some of the obstacle detection functions. Obstacle filters and confidence logic are also implemented to limit the number of false obstacles and to integrate the obstacles from the various perception sensors. The type of filtering and selection logic used is tailored to the sensors and the known sensor characteristics.

1.1.2.3 Behavior Management

The behavior management module is the central "brain" of the system. Its purpose is to monitor and react to dynamically changing conditions. This module receives input from the real-time path planner, obstacle database, navigation sensors and the vehicle interface module.

Several behaviors have been designed into the behavior module, using a state transition architecture. When a specific event or a change from normal operating conditions is detected, one of the behaviors is activated to handle the situation at hand. Each behavior executes an ordered list of instructions, providing a set of commands to the vehicle controller.

Some of the conditions the behavior module will react to are as follows:

- **Transition in E-Stop state:**
When the e-stop is in Pause mode, a behavior will command the vehicle to come to a stop. When e-stop transitions to Run, another behavior is initiated to begin normal operation.
- **No valid path ahead:**
The behavior initiated in this condition commands the vehicle to come to a stop and wait for a valid path. If no valid path is found, it will command the vehicle to back up and try again.
- **Obstacle detected behind the vehicle while backing up:**
Another behavior will stop the vehicle and command it back into normal operation to try to find a valid path ahead.
- **A large course change requiring a backup maneuver:**
The switchback behavior guides the vehicle around a 3-point turn.
- **Narrow tunnel condition:**
The tunnel behavior will guide the vehicle through a narrow tunnel, using the LIDAR scan data.
- **Stuck between obstacles:**
If the vehicle cannot make progress along the route because it continues to go back and forth, getting stuck between obstacles, the stuck behavior will take over. It will first try to position the vehicle at different angles to search for a valid path. If no valid path is found, it then commands the system to ignore low confidence obstacles, in an attempt to eliminate false obstacles. The last resort is to go forward toward the DARPA route, ignoring all obstacles.

1.1.2.4 Navigation

Two Oxford Technical Solutions (OXTS) RT3100s supply GPS position information to the VMS system. The RT3100 is a combined GPS/IMU sensor that provides real-time data even in the absence of GPS signal. The high 100Hz update rate has a very low latency to insure that the system is using the most accurate position possible. One RT3100 is configured to use DGPS corrections transmitted via RS-232 from an external GPS receiver subscribed to the Omnistar correction service. The other RT3100 is configured to use WAAS corrections.

In the case of loss of GPS signal, such as driving through a tunnel, the IMU portion of the RT3100 takes over and begins dead reckoning. In order to aid the INS solution in dead reckoning mode, a wheel speed sensor on the vehicle provides input to the RT3100. Tests have shown that the wheel speed input helps to keep the IMU solution stable and extends the time the RT3100 is able to dead reckon.

In the case of a failure or short-term loss of the RT3100's, a second dead reckoner is implemented using sensed wheel speed and wheel angle. The sensed data are received from the

vehicle over a CANBus and represents an independent backup navigation function. Because of the potentially large errors that can build up when in this degraded mode, RDDF boundary area checks in the path planner are disabled so the vehicle can continue to navigation relative to the terrain and terrain obstacles for short periods of time.

1.1.2.5 Graphical User Interface

The Graphical User Interface (GUI) provides multiple functions to the user including a graphical real-time data viewer, a state simulation, and a data-recording tool with playback capabilities. The GUI is primarily a development tool and is not considered to be part of the integral real-time VMS system. The GUI is also used to initialize the system but the GUI is not required to be running for the VMS to operate properly.

The primary function of the GUI allows users to view the state data, truck commands, truck location, control data, path, and course data from the RDDF file, all in real-time. The user can also start sensor applications individually (SICKS, IBEO, stereo vision, and the real-time path planner/vehicle manager) and view their respective data (obstacles, vision grid, path tree, etc). In addition to viewing this data, the user can record the data for each associated function for playback and simulation.

1.1.3 Sensors

The sensors were carefully selected to provide the required navigation and perception capability. The sensors selected for the DARPA Challenge 2005 are as follows:

- Oxford GPS/INS
- Trimble GPS
- SICK LIDAR
- IBEO LIDAR
- Parma Vision System

1.1.3.1 Oxford GPS/INS

The OXTS RT3100s are mounted on the floor of the cab on the approximate centerline of the vehicle. During most of the integration and development testing, the antennas for the RT3100s were mounted on the roof of the cab on an aluminum sheet ground plane. For the actual race, the cab was reduced in height and the antennas were mounted on the roll bar just behind the cab. The small patch antennas that were initially used with the RT3100s, were replaced later in the testing phase with GPS-701 antennas from Novatel. It was discovered that the small patch antennas seemed particularly susceptible to interference. In order to obtain a more accurate position solution and eliminate any errors over time, the position solutions from the two RT3100s were averaged together. In the case of a failure of one of the RT3100s, the system will switch to using the remaining RT3100 as the sole GPS source.

The RT3100 system has configuration software that allows the user to custom tailor the available options. Also included with the RT3100 system is a software package that allows the user to monitor the status of the RT3100s in real-time and post-process data gathered during testing.

1.1.3.2 Trimble GPS

The Trimble GPS is an agriculture GPS unit used receive differential corrections used by the GPS receives embedded in the Oxford RT3100's. The model used is an AgGPS132. The Trimble receiver outputs differential corrections at 1Hz to through RS232. In order to output the differential corrections the Trimble receiver is placed in base station mode and must also have a subscription to OmniStar.

1.1.3.3 SICK LIDAR

There are three SICK LMS-291 LIDARs used for positive and negative obstacle detection. The two forward facing SICK LIDARs are mounted on the outermost edges of the front rollbar. They are pointed 10 degrees down and 25 degrees outward from the truck so that there is good coverage on extreme turns. The rear facing LIDAR is mounted near the cargo bed height in the middle of the truck and is pointed down for negative obstacle detection.

Scan data from the SICK LIDARs is received via a RS-232 connection. The SICK LIDARs are configured to scan a 100-degree scan area with a 1-degree resolution. We then use three separate algorithms for negative edges (cliffs), positive and negative obstacles at close range, and path center detection.

1.1.3.4 IBEO LIDAR

The IBEO ALASCA LIDAR is a 4-plane scanner that is used for positive obstacle detection. The IBEO LIDAR is mounted level in the front bumper and has two planes that scan toward the ground and two planes that scan toward the sky. With a range of 80 meters and a resolution of 0.25 degrees the IBEO can detect obstacles accurately at long and close range. The 240-degree scan area allows the IBEO to see obstacles around upcoming turns.

The IBEO LIDAR sends scan data via Ethernet to the LIDAR PC via a TCP connection. Our algorithm then transforms the raw scan data into obstacles by looking for large positive slopes in the scan data. Obstacles are then sent to the information store database for later use and comparison with other sensor data

1.1.3.6 Parma Vision System

The vision system is comprised of a forward-looking system and a backward looking one. Both systems share the same technology and processing: color cameras and stereoscopic vision.

The forward-looking system consists of three identical cameras mounted on a rigid bar on top of the hood. The two lateral cameras lay at a distance, which is about 1.5 meters, while the central one is placed asymmetrical at about 0.5 meters from the right one. Thanks to a precise calibration of the cameras -performed on a graduated grid- the three degrees of freedom specifying cameras orientation are fixed to known values, and in particular – in order to ease the subsequent processing- the yaw and roll angles are fixed to zero for all cameras. The pitch angle is chosen so that the cameras frame a small portion over the horizon (to limit direct sunlight) and frames the terrain at about 4 meters from the vehicle.

The trinocular system sends 3 video streams at 10Hz (640x480, color with Bayer pattern) to the vision PC via a firewire connection. The PC selects which stereo pair to use depending on the speed of the vehicle. Since the baseline of the stereo vision system influences the depth of view, the large baseline is used at high vehicle speeds so that a deeper field of view is obtained, the medium one at medium speeds, and the short baseline is used at low speeds.

Pairs of stereo images are used for both obstacle detection and path detection.

Image disparity is first used to estimate the average terrain slope in front of the vehicle. Slope information is then used for both obstacle detection and path detection. Any significant deviation from the average smooth slope detected previously is then identified as an obstacle. The exact location of obstacles is then obtained via stereo triangulation between the two views of the object. A fairly precise localization is obtained, but nonetheless it is further refined via sensor fusion with raw data coming from a laserscanner placed into the front bumper. In this way it is possible to detect thin vertical posts and fence poles; the laserscanner will then improve the quality and precision of this information via a direct measure of the shape and distance to the obstacle.

Image disparity is also used to compute the area in front of the vehicle which features a smooth slope, the so-called free-space. The free-space is one of the features that concur to construct a representation of the path to be followed by the vehicle: also similarity in texture, similarity in color, and shape information are taken into account, fused together, and delivered to the following path planning module.

Vibrations are automatically filtered out since the slope detection algorithm, which is the first to be performed, also extracts information that are used to electronically stabilize the oncoming images. Different light levels are compensated for by the automatic gain control of the cameras.

The camera boxes have a sunshade that should reduce to a minimum the quantity of direct sunlight hitting the cover glass, in order to avoid over saturation and reflections due to dirty glass. The glass is periodically cleaned with a spray of air and/or water to eliminate dust.

1.1.4 Pre-Mission Planner

The Pre-Mission Route Planner software system was designed to provide the team with the following capabilities: 1) Review of route on photo-realistic 3D terrain model, 2) Optional insertion of additional micro-waypoints, and 3) Optional adjustment of maximum vehicle speed at any waypoint while accounting for the vertical profile at its vicinity. The software system consists of a combination of commercial off-the-shelf (COTS) software and custom-built software. Three stages of operation are planned leading up to race day execution: (1) Acquisition and processing of geographic information system data into a 3D terrain model, (2) Division of DARPA waypoints into adjoining split routes and computation of corridor boundaries, and (3) Interactive review/editing of split routes before merging back into a single route file.

In the first stage, both high-resolution terrain elevation data and geo-referenced image data is acquired. The elevation data chosen is 1/3 arc second National Elevation Data (NED) from

USGS. The image data consists of a combination of 1m Digital Orthographic Quadrangle (DOQ) data from USGS, and 2 ft color image data from AirPhoto USA. The TerraVista software from Terrain Experts then processes the data to produce a four levels-of-detail paging terrain (TerraPage format). Such paging terrain offers good real-time performance on a notebook PC, while preserving the geo image quality as close to their original resolution. Both ECW and dxt (supported by graphics hardware) texture image compression schemes will be used to reduce terrain archive storage requirement (by about 40%) and to speed up the terrain rendering.

In the second stage on race day, in-house developed software will be used to process the DARPA waypoint file (RDDF). The first step will be to augment the waypoints with elevation data. Global Mapper (COTS software) will be used to determine the elevation from the NED data. The 3D coordinates of corridor boundaries will be computed, and the entire route is split into a user-specified number of adjoining routes for individual editing in the third stage. The splitting strategy could be based on one of three choices: 1) Maintaining the same number of waypoints for each split route, 2) Maintaining the same length along each split route, or 3) A weighed combination of the first two options.

In the third stage on race day, each split route will be handed over to a human editor for review and possible editing. The editor will then assess his/her assigned split route and look for potential problems with the help of the in-house developed visualization/editing software. The vertical profile at the vicinity of each waypoint being examined is shown to alert him/her of potential speed problems. Maximum vehicle speed at each waypoint can be specified. New micro-waypoints can be inserted, deleted and moved interactively. In case of doubt over the terrain contour from sometimes-ambiguous geo image, the editor can then switch to a 3D exocentric view mode from the map view mode, to determine whether significant terrain drop or rise occur at the side of the route. When editing is complete, all edited split routes would then be merged back into a single route for upload to the vehicle.

2 Testing

The test plan includes individual testing of each sensor system on the vehicle as well as testing of the combined autonomous vehicle system. With all systems operational, the TerraMax vehicle will be run in the Barstow area for several weeks doing durability testing to eliminate any possible weak points in the system.

Testing of the TerraMax autonomous vehicle has been carried out in various kinds of weather at several different locations. This range went from January testing on snow covered, frozen ground in Oshkosh, Wisconsin, to August testing in the mid-day heat in the Stoddard Valley Off Highway Recreation Area in Barstow, California. Testing of the autonomous vehicle was also done at an off-road site near Cedar Rapids, Iowa, at the Nevada Automotive Test Center (NATC) near Carson City, Nevada, and at Road America near Elkhart Lake, Wisconsin. Up to 8 weeks of testing will be done in the Barstow area, which is closest to the conditions expected for the DGC Event.

An MTRV wrecker has been equipped with three front cameras for parallel testing of the vision system while in the Barstow area. An ISO container / command center is also being used to

coordinate the testing of the TerraMax and wrecker while in the Barstow area.

2.1 Vehicle

The basic MTRV vehicle has been thoroughly tested during its original development for the military in a variety of terrains including those that would be typical to the DGC Event. Any modifications to the basic vehicle will be tested as part of the general overall testing of TerraMax.

Modeling and simulation of the TerraMax vehicle was done using ADAMS to determine vehicle performance over various size obstacles and to evaluate steering response at various vehicle speeds.

2.2 Vehicle Management System Software

The software was developed and testing in phases utilizing different test methods. These test methods included software peer reviews, simulations on host, lab testing, and testing on the vehicle.

Software peer reviews were held for code that was considered either complex in nature, or a critical interface between two functions. At each software review, members of the team were invited to review the code. Action and questions were formally documented for later investigation and resolution by the coder.

Rockwell also developed a simulation environment that included all of the vehicle dynamics. This simulation was used to test the vehicle control interface, real-time path planner and behavior control. Similar to on the vehicle, a series of waypoint could be executed while avoiding planned obstacles. The 2004 race path was executed several times in this simulation environment to determine if the vehicle could navigate the entire path.

Lab testing was used to test software on the real target hardware. Testing in the lab included resource utilization for memory and throughput, transmitting and receiving data over real buses between the different computers, and integration with real sensors.

Finally, the software was moved onto the vehicle for final testing.

3 Conclusion

Oshkosh Truck Corporation is back for the 2005 DARPA Grand Challenge and will, with its strategic partners, Rockwell Collins and University of Parma, continue to develop an autonomous navigation system on its MTRV medium-duty chassis – one the most mobile production trucks in the world.

In the 2004 competition, Team TerraMax was one of only 7 teams to successfully navigate the QID and managed 1.2 miles on the race course before being "confronted" by an impassible bush.

Armed with the knowledge gained in their first attempt, Team TerraMax will take their 15-ton cargo truck back to the desert - and this time - they're racing to win.

Oshkosh Truck, as a leader in truck technologies for the military, sees this challenge on a very practical level. Don Verhoff, Oshkosh's Executive Vice President of Technology explains "although design development may continue for years, the idea of a driverless convoy of defense vehicles to deliver supplies to the front line, never jeopardizing the welfare of a single driver, is closer than one might imagine."

As pioneers in many of the advancements found on the MTRV, including the TAK-4® independent suspension system, central tire inflation system and Command Zone™ advanced electronics – Oshkosh possesses a unique synergy with DARPA's goal to provide driverless supply lines to the U.S. military.